

**INTERNATIONAL ENERGY AGENCY  
COAL INDUSTRY ADVISORY BOARD**

**INDUSTRY PERSPECTIVES ON INCREASING THE EFFICIENCY  
OF COAL-FIRED POWER GENERATION**

**Ian M. Torrens**  
**Shell Coal International**

**&**

**William C. Stenzel**  
**SEPRIL Services**

**ABSTRACT**

*Independent power producers will build a substantial fraction of expected new coal-fired power generation in developing countries over the coming decades. To reduce perceived risk and obtain financing for their projects, they are currently building and plan to continue to build subcritical coal-fired plants with generating efficiency below 40%. Up-to-date engineering assessment leads to the conclusion that supercritical generating technology, capable of efficiencies of up to 45%, can produce electricity at a lower total cost than conventional plants. If such plants were built in Asia over the coming decades, the savings in carbon dioxide emissions over their lifetime would be measured in billions of tons.*

*IPPs perceive supercritical technology as riskier and higher cost than conventional technology. The truth needs to be confirmed by discussions with additional experienced power engineering companies. Better communication among the interested parties could help to overcome the IPP perception issue. Governments working together with industry might be able to identify creative financing arrangements which can encourage the use of more efficient pulverised clean coal technologies, while awaiting the commercialisation of advanced clean-coal technologies like gasification combined cycle and pressurised fluidised bed combustion.*

**EXECUTIVE SUMMARY**

- New generating capacity required globally between 1993 and 2010 is estimated to be around 1500 GW, of which some two-thirds will be outside the OECD, and some 40% in the Asian non-OECD countries. Coal is likely to account for a substantial fraction of this new generation, and with liberalisation of electric power markets driven by the need for inward investment, independent power producers are likely to build a substantial number of the coal-fired power plants in developing countries.

- Today's state-of-the-art supercritical coal-fired power plant has a conversion efficiency of some 42-45%, about 5 percentage points higher than that of the conventional subcritical plants which continue to be built in most projects in non-OECD countries. If supercritical plants were to be built instead, the amount of incremental carbon dioxide not released to the atmosphere over the next few decades as a result of electricity generation would be measured in the billions of tons, without constraint on energy and economic growth. Depending on the generating efficiencies achieved, the CO<sub>2</sub> emission reductions over the lifetime of the plants built during one decade of growth in Asia alone could amount to 5-10 billion tons.
- With more than 350 supercritical units operating world-wide today, and more than two decades of experience and development of this technology, their reliability today is assessed by authoritative observers and operators of power plants to be at least as good as that of conventional sub-critical plants.
- A new engineering assessment by an international power engineering firm concludes that the capital cost increase associated with a supercritical or ultra-supercritical pulverised coal power plant compared to a conventional subcritical plant is small to negligible. The reason is that capital cost increases specific to the supercritical plant (e.g. associated with superior materials and other design features) are counter-balanced by the capital cost savings associated with the fact that the boiler and ancillary equipment can be smaller due to the increased efficiency.
- The increased efficiency associated with the supercritical plant leads to an actual reduction in the total cost of electricity generated in cents/kWh, relative to a conventional plant. In fact, depending on fuel price, an ultra-supercritical plant with flue gas desulphurisation, selective catalytic reduction for post-combustion NO<sub>x</sub> control, and a high efficiency baghouse for particulate control, can produce marginally cheaper electricity than a conventional subcritical plant with only an electrostatic precipitator for particulate control.
- Despite this, the independent power sector continues to build subcritical plants and has no near-term plans to increase the efficiency of power plants in the projects it is developing. There is a clear perception among IPP companies that supercritical technologies are both more expensive and contain more risk than subcritical technologies. Part of the reason for this appears to be innate conservatism among their technology suppliers and project financiers.
- IPP companies' decision-making is driven primarily by the issues of reliability, technology cost, government regulation, and lender attitudes or financing constraints. Generating efficiency is perceived to be of second-order importance.

- Advanced clean coal technologies such as integrated gasification combined cycle and pressurised fluidised bed combustion will be selected for independent power projects only in very specific circumstances, where their technology and other risks are fully covered and their incremental costs are recovered in the price of electricity. Market penetration on a wider scale is seen by the IPPs as being in the 2005-2010 timeframe or beyond.
- It appears that the only way to accelerate this is to complete a number of successful demonstrations which, in particular, show that advanced clean coal plants can be operated reliably and with superior performance, and specifically that their present estimated capital costs can be reduced substantially to a point where they are competitive with state-of-the-art pulverised coal technologies. These second- or third-of-a-kind demonstrations are likely to require financial support by governments if they are to be realised.

## **I. INTRODUCTION**

The CIAB's Global Climate Committee was asked by the IEA to assess the evolution of energy-efficient coal-fired power generation in non-OECD countries.. The primary market for coal over the coming decades will be electricity generation, especially in the newly industrialising countries of the developing world. Estimates of the amount of new generation required between 1993 and 2010 are in the region of 1500 GW, of which more than 700 GW are in the non-OECD countries (Figures 1, 2). Coal is expected to account for a large proportion of new electricity generation (Figure 3).

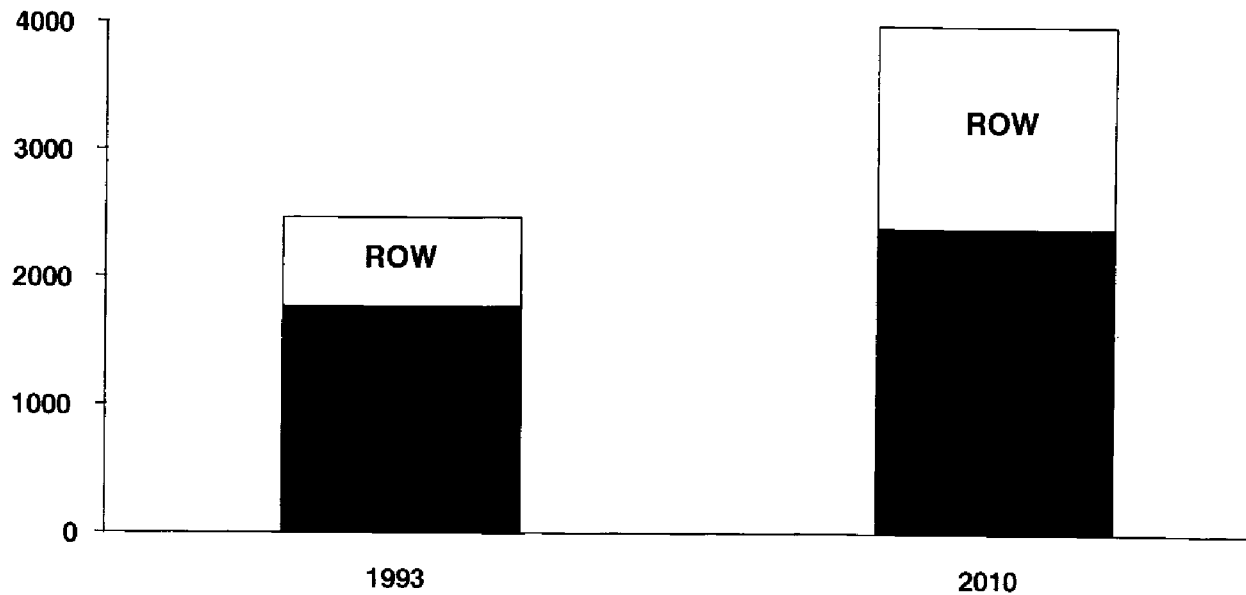
The global issues of sustainable development and the enhanced greenhouse effect are topics of importance to IEA Member governments and CIAB members. Coal, as a fossil fuel with a reserve base measured in centuries rather than decades, is an important part of the global economic-energy-environment equation. It is clear that for the newly industrialising economies to sustain the major growth phase now in progress, coal must play its part as an efficient and environmentally sound source of energy.

Today's state-of-the-art supercritical pulverised coal-fired power plant has a conversion efficiency of some 42-45% (lower heating value - LHV), about 5 percentage points higher than that of the conventional subcritical plants which continue to be built in most projects in non-OECD countries. The main question addressed by this paper is, what would be needed to have state-of-the-art technology accepted for new power projects in these countries? If this were achieved, the amount of incremental carbon dioxide not released to the atmosphere over the next few decades as a result of electricity generation would be measured in the billions of tons, without constraint on energy and economic growth.

The necessary growth of electricity generation capacity in the industrialising countries will require very substantial inward investment. In order to attract this investment, generation of electricity is

# Figure 1

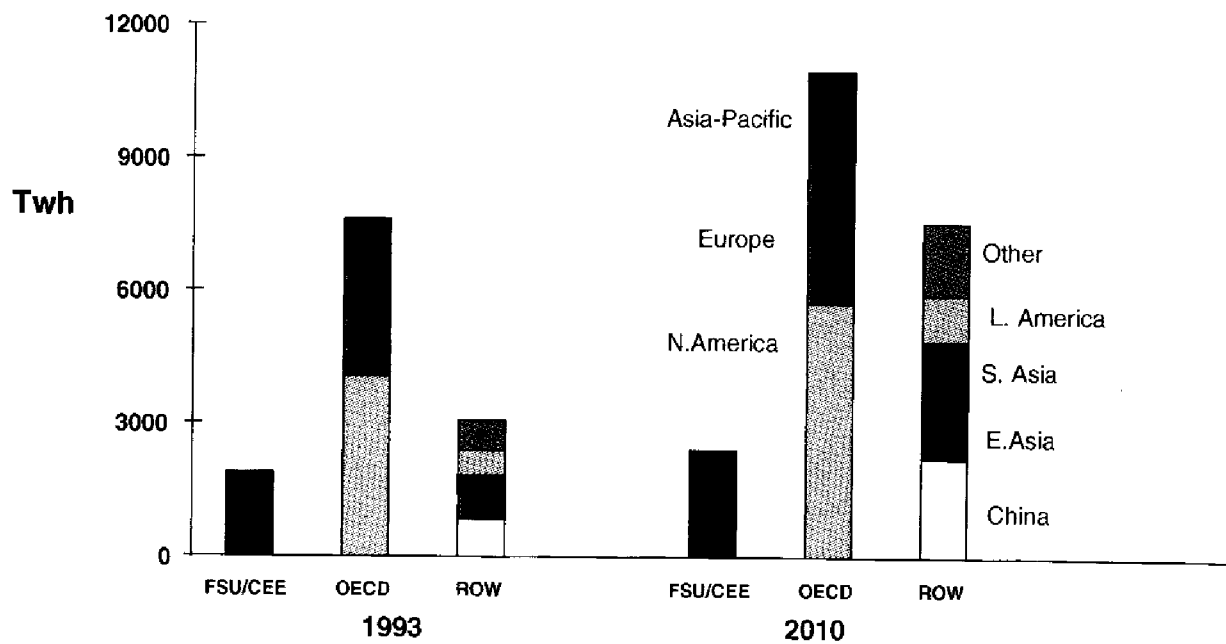
## Electricity Generating Capacity Growth (GW) 1993 - 2010



Source : IEA World Energy Outlook 1996

# Figure 2

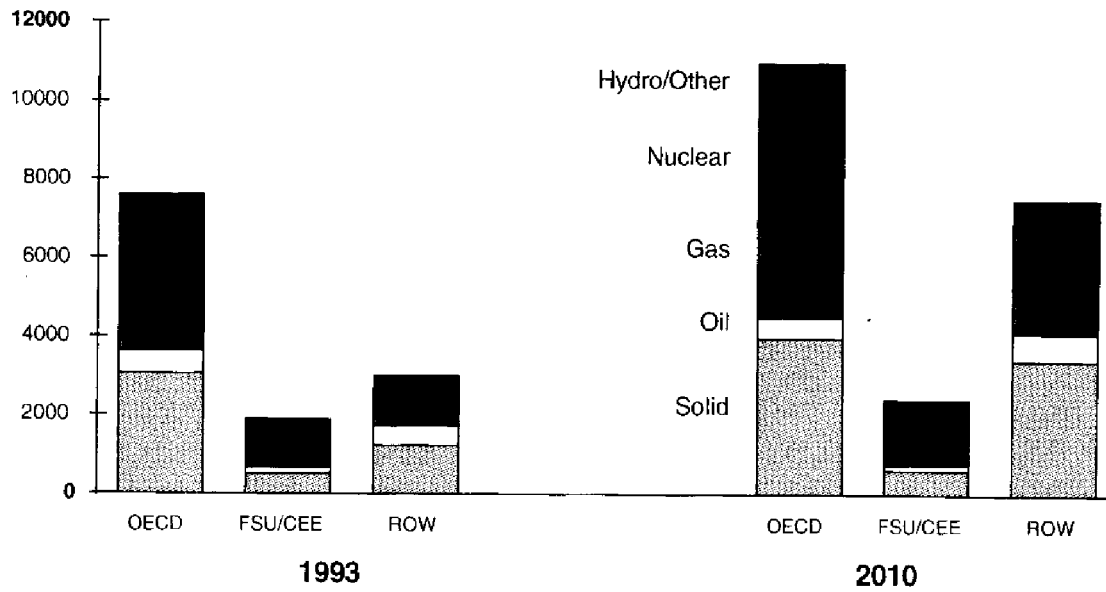
## Electricity Output by Country/Region(TWh) 1993 - 2010



Source : IEA World Energy Outlook 1996

# Figure 3

## Primary Energy Shares in Power Generation (TWh) 1993 - 2010



Source : IEA World Energy Outlook 1996

being privatised in an increasing number of countries. The involvement of independent power producers (IPPs) in private power projects in a number of countries is an important part of this process.

The CIAB took a two-pronged approach to the issues related to improving generating efficiency in new coal power generation in non-OECD countries. A consultant, SEPRIL, jointly owned by the Electric Power Research Institute and Sargent & Lundy), was engaged to provide an analysis of costs and other issues in the comparison of subcritical, supercritical and ultra-supercritical pulverised coal plants in these countries. At the same time, in order to benefit from the insights which IPPs have gathered as a result of their experience to date in private power projects and business development in newly industrialising countries, the CIAB designed a relatively simple survey by telephone interview. The most appropriate people to respond to such a survey were identified and the interviews carried out between April and July 1996.

The results of the IPP Survey are summarised in the next Section. The findings of the cost and performance comparative analysis are presented in Section III.

## **II. OVERALL SUMMARY OF SURVEY RESULTS**

A total of fourteen companies took part in telephone interviews and/or provided written responses to the CIAB Questionnaire. The companies taking part in the Survey were:

ABB Carbon	AES Corporation
Babcock and Wilcox	Black and Veatch
Community Energy Alternatives	CMS Generation
Duke Energy	Edison Mission Energy
Elsamprojekt	Entergy Power Systems
IVO Energy International	National Power
NRG Energy	Southern Electric International

The majority of those interviewed represented independent power producing companies involved in developing power projects in non-OECD countries. However, representatives of several power engineering/construction companies and technology suppliers also participated. Those who agreed to take part in the Survey were assured that the anonymity of their responses would be protected, and that the results of the Survey would be shared with them as soon as possible.

There was a high degree of consensus among the participants in their response to the questions, which makes it relatively simple to draw broad conclusions. The main lessons to be drawn from the Survey are the following:

## 1. Technologies used or foreseen

The vast majority of projects use or plan to use sub-critical pulverised coal technologies for larger plants, with some smaller projects using atmospheric fluidised bed combustion (AFBC) technology. Supercritical pulverised coal technology is viewed as technically commercialised but riskier and more costly, and needing incentives such as high priced fuel to be the technology of choice. Pressurised fluidised bed combustion (PFBC) and integrated coal gasification combined cycle (IGCC) technologies may be used in special circumstances (e.g. government support) in the coming years, but are unlikely to come into widespread use by IPPs until 2005-2010 or beyond.

## 2. Environmental Requirements

The World Bank Environmental Guidelines play a major and increasing role in most countries. Most IPPs and developing countries are aware of a 1995 draft of these which is stricter than the 1988 official version, and believe these new guidelines will be implemented shortly. Some IPPs have corporate environmental guidelines which go beyond the World Bank ones; however, to go too far beyond raises economic competitiveness issues.

## 3. Main Factors influencing Technology Selection

The results of a poll included in the Survey, on the principal factors influencing technology selection and their relative importance in decision-making, are shown in Table 1 below.

TABLE 1																
CIAB IPP Survey Responses																
Impact of Different Factors on Coal Power Generation Technology Selection																
1 = Not important      5 = Extremely important																
Response No.	1	2	3	4	5	6	7	8	9	10	11	12	14	15	Mean	S.D.
Environment	4	4	3	4	2	4	5	3	4	3.5	4	4	5	5	3.9	0.83
Efficiency	4	3	3	4	2	3	4	3	5	4.5	3	5	4	3	3.7	0.9
Reliability	4	4	4	5	5	5	4.5	5	5	5	3	5	4.5	5	4.6	0.6
Maintainability	3	5	4	5	4	5	4	5	4	4	3	4	4	5	4.2	0.68
Technology Cost	5	5	5	4	4	5	5	4	5	5	5	4	3.5	5	4.6	0.55
Technology Maturity	3	4	4	4	5	3	4	4	4	4	4	5	3	5	4	0.65
Technology Risk	3	4	4	5	5	3	3	4	4	4	4	4	5	5	4.1	0.7
Build Time	4.5	4	3	4	3	3	3	3	5	4	3	4	3	3	3.6	0.78
Fuel Flexibility	2.5	4	2	4	2	3	5	3	3	3	3	5	5	2	3.3	1.07
Operational Flexibility	3	3	3	4	2	3	3	3	4	3.5	3	4	3	3	3.2	0.56
Need for Skilled Operators	3	4	1	3	3	4	3	3	3	3.5	3	4	3	5	3.3	0.88
Customer Specifications	4	5	5	4	5	2	3	3	4	4	3	4	3	3	3.7	0.88
Financing Constraints	4.5	5	4	4	3	5	5	4	5	5	4	5	5	5	4.6	0.62
Lender Attitudes	4	4	3	4	4	4	5	4	4	4	4	5	5	3	4.1	0.59
Government Regulation	3.5	4	5	5	4	5	5	4	5	5	4	5	5	1	4.4	1.08

S.D. = Standard Deviation

Reliability, technology cost, and financing constraints were voted the most important factors (averaging 4.6 on a scale of 1 to 5 in importance). The standard deviation in the responses was relatively small, of the order of 0.6, indicating a strong consensus on these factors. The next most important factors were government regulation (4.4), maintainability (4.2), technology risk and lender attitudes (both 4.1), technology maturity (4.0), and environment (3.9). Interestingly, the need for skilled operators scored relatively low in the poll (3.3), the IPP view being that it is relatively easy to find and train operators.

#### **4. Power Plant Conversion Efficiencies**

Most coal-fired power plants being planned or built today use sub-critical technology and have conversion efficiencies in the range of 37-39% on a lower heating value (LHV) basis (9200-8700 Btu/kWh). Responses on future trends in efficiency over the next 5-10 years were mixed, though few expect increases of more than a few percentage points.

#### **5. What it would take to improve Generating Efficiencies**

The present cost of fuel in non-OECD countries is perceived to be a disincentive to achieving significant increases in generating efficiency. Only when fuel is expensive will competitive pressures by themselves lead to efficiency improvements. Stricter environmental requirements could play a role (especially constraints on carbon dioxide emissions). Governments can mandate efficiency standards, but this is not seen as likely unless there is a strong national or international reason for doing so.

There is a common perception of higher capital and operating cost, and risk of reduced plant operating reliability, associated with supercritical pulverised coal technologies, both among IPPs themselves and, perhaps more important, among their engineering and technology supply partners. The latter are normally expected to bear the technology risk in an IPP project, which tends to bias them towards conservatism. Some of the higher cost may also in fact be due to the higher perceived risk premia in project-financed IPP plants. There may be an information gap here that could be bridged by further dialogue.

The responses to the IPP Survey have highlighted a perception that supercritical pulverised coal technology is both costlier and riskier than conventional subcritical technology. How justified is that perception? The other part of this assessment, described in Section III. below, attempts to respond to this question.

### **III. Comparison of Supercritical Versus Subcritical Plant performance**

In order to assess the cost-effectiveness and environmental performance of SC and USC coal-fired generating plants versus a "conventional" subcritical plant of the type used in most IPP projects today, an analysis of comparative performance and cost was carried



out using the SOAPP data-base, for a 600 MW PC-fired plant in an Asian location. The plant capacity factor is 81%. The coal sulphur content is 0.9%.

For this case study, the following scenarios were evaluated:

- (1) 2400 psig subcritical plant with an electrostatic precipitator for particulate control and low-NO<sub>x</sub> burners, but no post-combustion sulphur or nitrogen oxide controls (Conventional Plant).
- (2) 3500 psig supercritical plant (SC).
- (3) 4500 psig ultra supercritical plant (USC).
- (4) 4500 psig ultra supercritical plant with spray dryer FGD, SCR, and baghouse for particulate control (USC w/FGD, SCR).

The analysis was carried out for two variants of capital cost and for two types of coal. The higher level of capital cost ( ~\$800/kW for a subcritical plant without FGD) corresponds to that for a plant built in an advanced OECD country, and the lower capital cost (~\$620/Kw) to that for a similar plant constructed in a developing country such as China. The lower priced coal (~\$15/short ton, heating value 7900 Btu/lb) might be that for a minemouth coal plant, and the higher coal price (~\$40/short ton, heating value 12000 Btu/lb) might be the landed price of internationally traded coal at a coastal power plant.

## **1. Plant Efficiency**

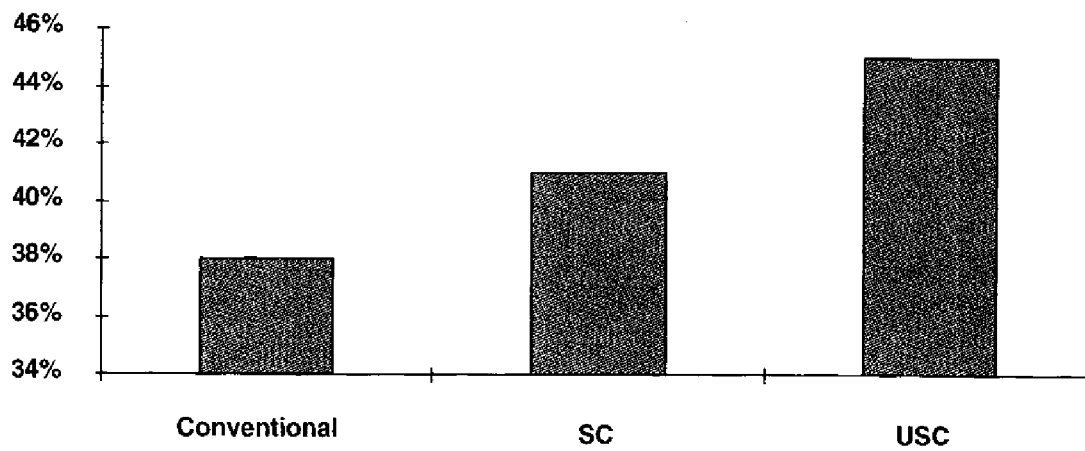
The plant efficiency comparison is shown in the Figure 4. Compared to the conventional subcritical plant's 38% efficiency, a supercritical plant can readily achieve 41% and an ultra-supercritical one 45% on an LHV basis. It would be possible for a subcritical plant to achieve greater efficiency via higher temperatures (up to about 40%). The "conventional" plant in this comparison, however, is intended to represent one typical of many IPP coal plants currently in operation, construction, or project development.

## **2. Fuel Consumption**

The plant efficiency improvements result in significant reduction in fuel consumption. A 600 MW conventional plant has a primary fuel feed rate (100% load) of ~ 750,000 lb/hr. The more efficient USC plant has a primary fuel feed rate of 645,000 lb/hr. This translates to over ~375,000 short tons/year of coal not combusted, which results in a fuel cost savings of approximately \$6 million/year for a USC plant vs. a conventional plant based on a fuel cost of \$15 per ton delivered (calorific value 7900 Btu/lb), or approximately \$10 million/year if the fuel cost is \$40/ton (calorific value 12000 Btu/lb).

## Figure 4

### Plant Efficiencies (LHV) Supercritical Versus Subcritical



### **3. CO<sub>2</sub> Emissions**

With the recent attention focused on the international greenhouse issue, emissions of CO<sub>2</sub> from coal-fired power plants have received increasing attention. The annual mass CO<sub>2</sub> emissions for the conventional, SC and USC plants are ~5.2 million short tons, 4.8 million tons, 4.4 million tons, respectively (Figure 5). This represents 8% emission reduction for the SC and 15% for the USC plant relative to the conventional subcritical technology. Consequently, even the intermediate step of the supercritical plant reduces CO<sub>2</sub> emissions by almost a half million tons per annum for a 600 MW plant, or 0.7 million tons/GW. Over the 40 year lifetime of 1 GW of new coal generation, 28 million tons less CO<sub>2</sub> would be emitted. Asia alone may need to construct 15 GW per year of new coal generation over the next two decades, according to the IEA's World Energy Outlook (9). Thus one year's incremental generation would produce 420 million tons less CO<sub>2</sub> during its lifetime, and the savings from one decade of this growth would amount to almost 5 billion tons of CO<sub>2</sub>. And going to ultra-supercritical plants would double this. The stakes are clearly rather high.

### **4. SO<sub>2</sub> and NO<sub>x</sub> Emissions**

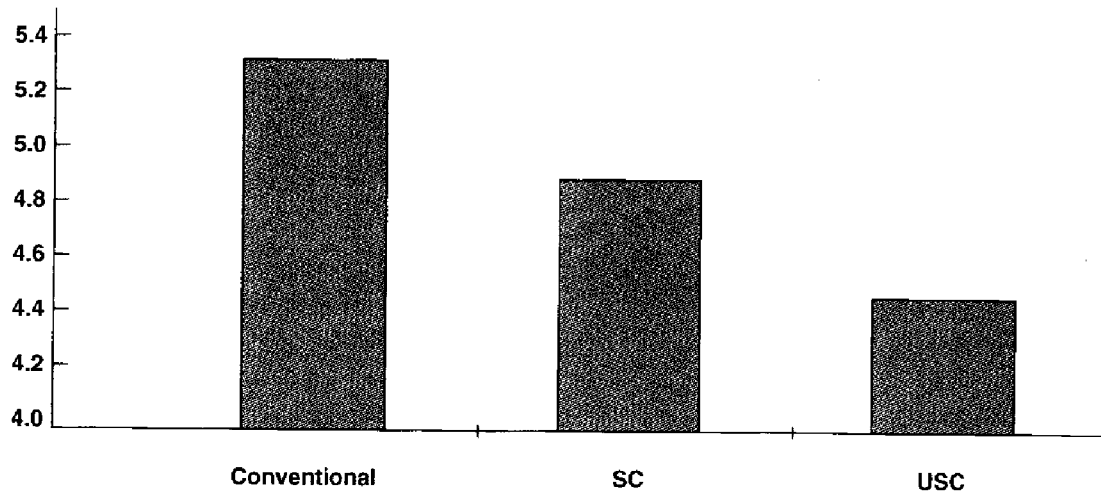
Emissions of gaseous pollutants are also reduced by building more efficient plants. The emission control equipment required for a plant depends on the coal selected and the applicable emission regulations. Currently, most plants in Asia are being installed without FGD Systems and with low NO<sub>x</sub> boiler burner equipment. This approach is based on the use of low sulphur coal, the cost, and current national air emission regulations or World Bank environmental guidelines. Emissions of both conventional pollutants (SO<sub>2</sub>, NO<sub>x</sub>, particulate, etc.) and carbon dioxide are lower for the more efficient supercritical plants than for the traditional subcritical plant. When comparing plants without post-combustion air pollution controls, mass emissions of SO<sub>2</sub> are reduced by 3300 tons/year, and emissions of NO<sub>x</sub> by 1180 tons/year for a USC plant compared to a conventional plant (Figure 6).

With the use of state-of-the-art air pollution controls, emissions of conventional pollutants can be reduced to ultra-low levels. The USC plant equipped with a lime spray dryer, SCR, and baghouse can produce emissions of 0.11 lb/MBtu SO<sub>2</sub>, 0.06 lb/MBtu NO<sub>x</sub>, and 0.005 lb/MBtu particulate. The emissions could be reduced by up to ~90% with this percentage sulphur coal. This low emissions boiler would be able to satisfy the most stringent regulatory requirements. The additional capital cost for this system on a 600 MW unit with low sulphur coal fuel (0.9%) would be approximately \$130/kW. This cost increment is relatively low because the spray-dryer/baghouse combination is substituted for the precipitator included in the other cases.

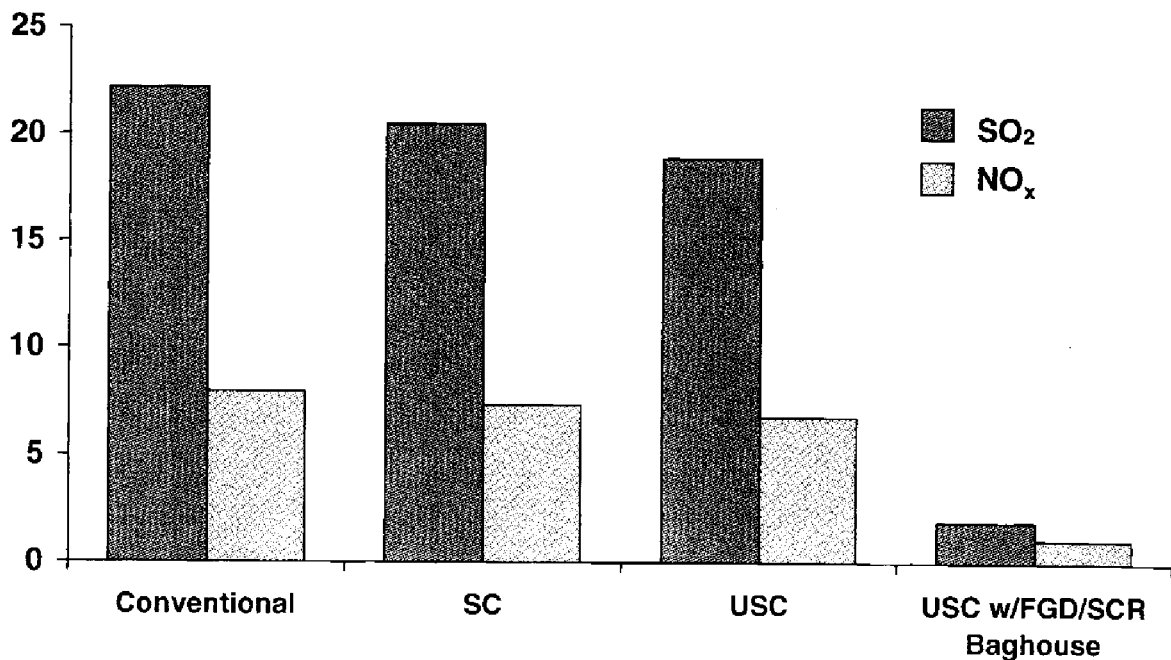
### **5. Plant Reliability**

Though this was not a variant in this assessment, it is worth a brief mention of the issue of supercritical versus subcritical power plant reliability. Experience with the higher

**Figure 5**  
**Carbon Dioxide Emissions**  
**(Million Tons/year, 600 MW Unit)**



**Figure 6**  
**SO<sub>2</sub> & NO<sub>x</sub> Emissions**  
**(1000 tons/year, 600MW Unit)**



temperatures and pressures involved in supercritical technology has grown substantially over the past two decades, and earlier technical problems have been to a large extent overcome by improvements in materials and design. There remain some corrosion problems stemming from the higher temperatures, which makes supercritical less suitable for high slagging or corrosion coals. Coal with greater than about 2% sulphur has caused some superheater and reheater difficulties. However, these difficulties are not necessarily specifically related to the sulphur content - coal chlorine and other constituents can have a major impact on the corrosion rates.

There are options which boiler manufacturers can employ with more corrosive coals to mitigate these problems. Boiler design optimisation options include a larger furnace for lower gas temperatures entering the reheater and superheater, use of higher alloy materials which have recently become available, tube shields, a tube cooling screen before the superheater and reheater, boiler water and steam circuitry to reduce high gas temperatures because of uneven gas and steam/water exchange in the combustion and other heat transfer zones, and other means.

Boiler tube leaks are a major issue for plant operation, often being the cause of loss of reliability. There is occasionally a tendency to generalise the difficulties caused by tube leakage problems, e.g. water wall leaks are not differentiated from superheater and reheater problems. However, tube leaks are often caused by water chemistry problems and not directly related to the coal quality. Many units have switched to "oxygenated" cycle chemistry, which has proven to reduce tube leaks very substantially.

It is possible that commercial risks for a supercritical plant burning greater than 2% sulphur coal might be subject to greater premiums owing to less historical experience. However, many of the plants to be built in Asia over the coming decades will use relatively low sulphur coal, so this issue may be only be encountered for plants attached to some specifically higher sulphur reserves.

#### **IV. COST COMPARISON OF SUPERCRITICAL VERSUS SUBCRITICAL PLANTS**

The capital costs differences (higher capital cost case) are shown in Table 2, which also separates out the main items for which the cost increases in the supercritical and ultra-supercritical plants relative to the conventional plant.

**Table 2. Capital Costs of Supercritical versus Subcritical Generating Plants**

		<b>Subcritical</b>	<b>Supercritical</b>	<b>Ultra-Supercritical</b>	<b>Ultra-Supercritical with FGD System &amp; SCR</b>
<b>\$/kW</b>					
Boiler (incl. steel, air heater, etc.)		\$142.94	\$153.09	\$163.52	\$163.52
% compared to base		Base	107.1%	114.4%	114.4%
Boiler plant piping		\$27.81	\$31.03	\$31.81	\$31.81
% compared to base		Base	111.6%	114.4%	114.4%
Feedwater systems		28.06	\$28.62	\$29.18	\$29.18`
% compared to base		Base	102.0%	104.0%	104.0%
Turbine-Generator		\$79.20	\$82.37	\$83.95	\$83.95
% compared to base		Base	104.0%	106.0%	106.0%
Turbine plant piping		\$16.25	\$15.44	\$15.43	\$15.43
% compared to base		Base	95.0%	95.0%	95.0%
Subtotal for boiler, turbine, high pressure piping, feedwater systems		\$294.26	\$310.38	\$323.91	\$323.91
% compared to base		Base	105.5%	110.1%	110.1%
Remainder of Plant		\$509.17	\$500.69	\$487.17	\$604.76
% compared to base		Base	98.3%	95.7%	118.8%
Total Plant Cost		\$803.43	\$811.07	\$811.08	\$928.67
% compared to base		Base	101.0%	101.0%	115.6%

The plant would have two units with low NO<sub>x</sub> burners, high efficiency particulate collection equipment, once through sea water cooling, including the switch yard and all the facilities for a new site location, and a 60 month construction schedule. The capital costs in Table 2 include the plant equipment, structures, switchyard, and coal unloading facilities.

The increases in cost for the higher pressure cycles plants are not as high as was evident in previous evaluations performed several years ago, because of better materials, equipment designs and other technological knowledge, and growing experience with the higher pressure and temperature cycles. Another factor is the beneficial impact of the higher efficiency cycle on the overall plant costs, in the form of reduced costs for smaller coal handling systems, precipitators, and cooling systems, etc. These cost reductions offset the increased costs for the higher pressure and temperature cycle boiler, turbine, piping, pump, feedwater heater, etc. equipment. This is shown graphically in Figure 7.

It is of course a valid question as to whether the substantial cost savings realised during recent years in subcritical plant design and construction may not be easily translated to supercritical and ultrasupercritical designs. While it is unlikely that plant designs for supercritical have reached the same "off-the-shelf" sophistication which the construction engineering firms now offer for subcritical plants, there is no a priori reason why the same competitive forces which led to these offerings should not come into play as soon as there is a demand for cost-effective supercritical plants.

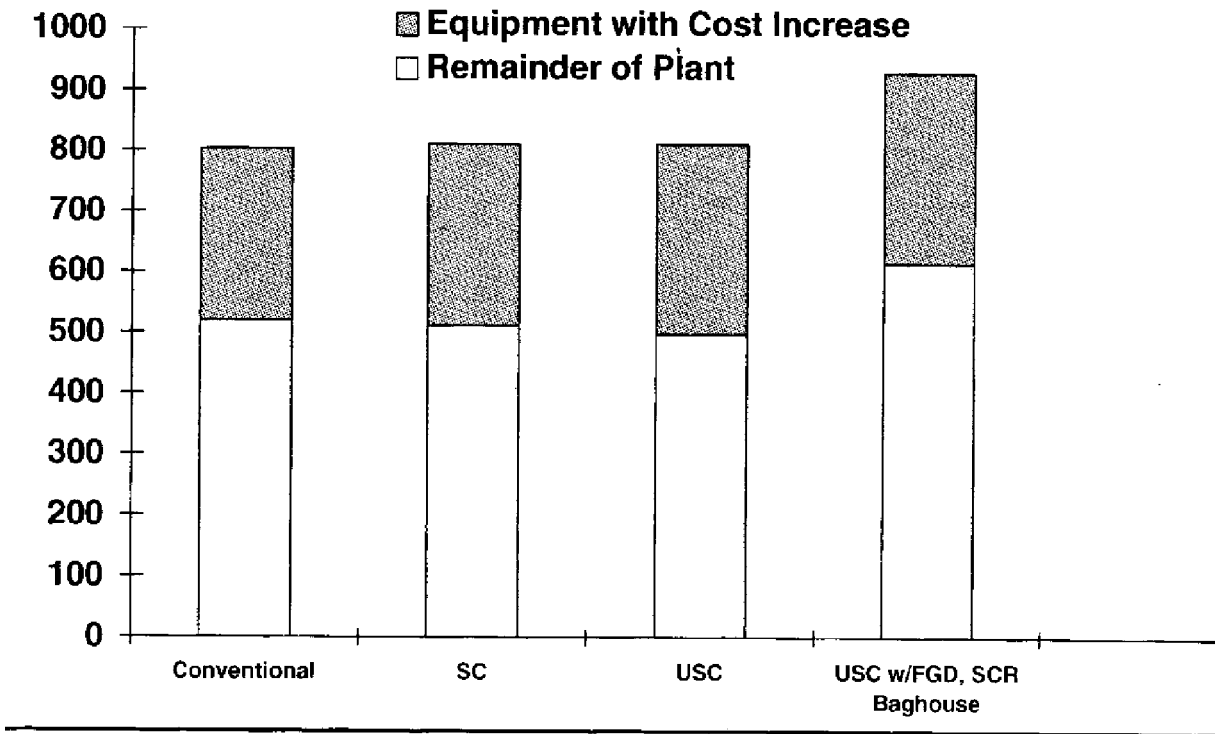
Table 3 summarises the economic parameters used to calculate the cost of electricity generated from the different types of plant.

**Table 3. Economic Parameters uses in the Comparison**

Plant Operating Period = 30 Years	Fuel Cost A = \$15.20/ton, B = \$40/ton
Plant Operating Hours = ~ 85% availability	Interest during construction = 9.8%
Capacity Factor = ~80%	O&M Escalation 2%
Fixed Charge Rate = 13%	\$5/ton Waste Disposal Costs
O&M (fixed) = ~ \$13/kW-year	

Capital charges and fixed O&M are higher for the SC and USC cycles, while total fuel costs are lower for the SC and USC because of the higher efficiencies. The O&M cost estimate was developed using the methods and data typically used for economic comparisons for new projects. The average availability for all three pulverised coal generating cycles included in this study is 85% and the capacity factor for all the units is 80%. This target is based on data from existing plants.

**Figure 7**  
**Capital Cost Comparison for**  
**2x600 MW Coal Fired Powerplant**  
**Higher Capital Cost Case**





The results are shown in Figure 8(a) and (b) for the lower coal price and Figure 9(a) and (b) for the higher coal price. In each of these Figures, (a) is the higher capital cost case and (b) the lower capital cost case. As expected, the effect of fuel price is very significant. When the higher level of capital cost is used in the analysis, going from conventional to supercritical in the lower coal price case reduces the electricity cost by 0.08 cents/kWh, and in the higher coal price case by 0.23 cents/kWh - almost a factor of three. The corresponding reductions in going from conventional to ultrasupercritical are 0.14 cents/kWh in the lower coal price case and 0.48 cents/kWh in the higher coal price case. Figure 9 shows that the ultrasupercritical plant with state-of-the-art sulphur and nitrogen oxide controls and a high efficiency baghouse for particulate control can produce cheaper electricity than a conventional plant with only a precipitator for particulate control!

When the lower capital cost is used in the analysis, the corresponding reductions in going from conventional to ultrasupercritical are 0.15 cents/kWh in the lower coal price case and 0.46 cents/kWh in the higher coal price case, implying that the choice of whether to use subcritical or supercritical technologies is not very sensitive to general capital cost levels.

## **V. CONCLUSIONS**

The independent power sector has been and remains reluctant to employ advanced clean coal technologies for power generation projects. The current standard appears to be a subcritical pulverised coal plant with flue gas clean-up adequate to meet World Bank Environmental Guidelines. Only minor improvements in generating efficiency are expected by the IPP sector over the next five years.

Advanced clean coal technologies like PFBC and IGCC are expected by independent power producers to be selected only in special cases where their risks are fully covered and incremental costs recovered in the price of electricity produced. Their market penetration on a wider scale without special treatment is seen by the IPPs as being in the 2005-2010 timeframe or beyond. It appears that the only way to accelerate this is to complete a number of successful demonstrations which, in particular, show that advanced clean coal plants can be operated reliably and with superior performance, and specifically that their present estimated capital costs can be reduced substantially to a point where they are competitive with state-of-the-art pulverised coal technologies.

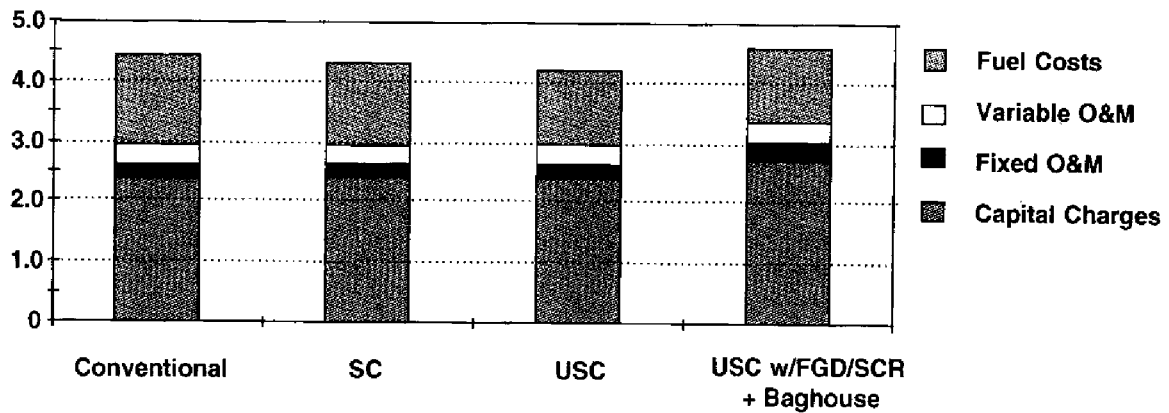
Supercritical pulverised coal technology is perceived as available but more costly and containing added risk in terms of reliability. Also, there are few incentives to employ it in non-OECD countries, especially where coal is inexpensive. There appears to be a perception problem, possibly due to lack of information, which may need to be addressed by the IEA and others, if the advantages of supercritical generating efficiency improvements, both environmental and economic, are to be realised in the near future.

## Figure 8 (a)

### Cost of Electricity (cents/kWh)

Lower Fuel Cost (\$15/ton)

Higher Capital Cost Case

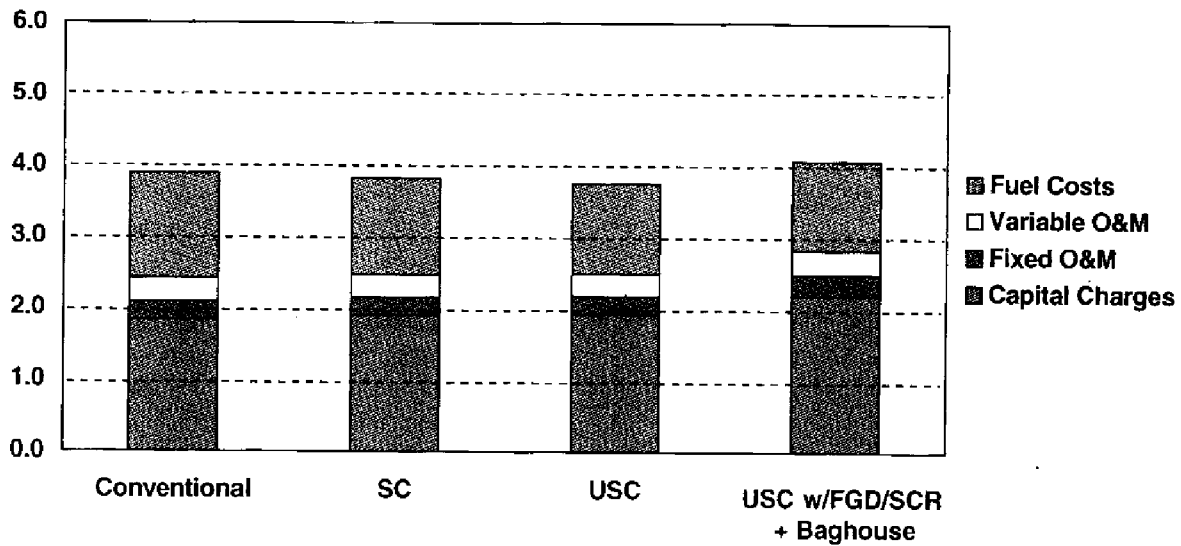


## Figure 8 (b)

### Cost of Electricity (cents/kWh)

Lower Fuel Cost (\$15/ton)

Lower Capital Cost Case

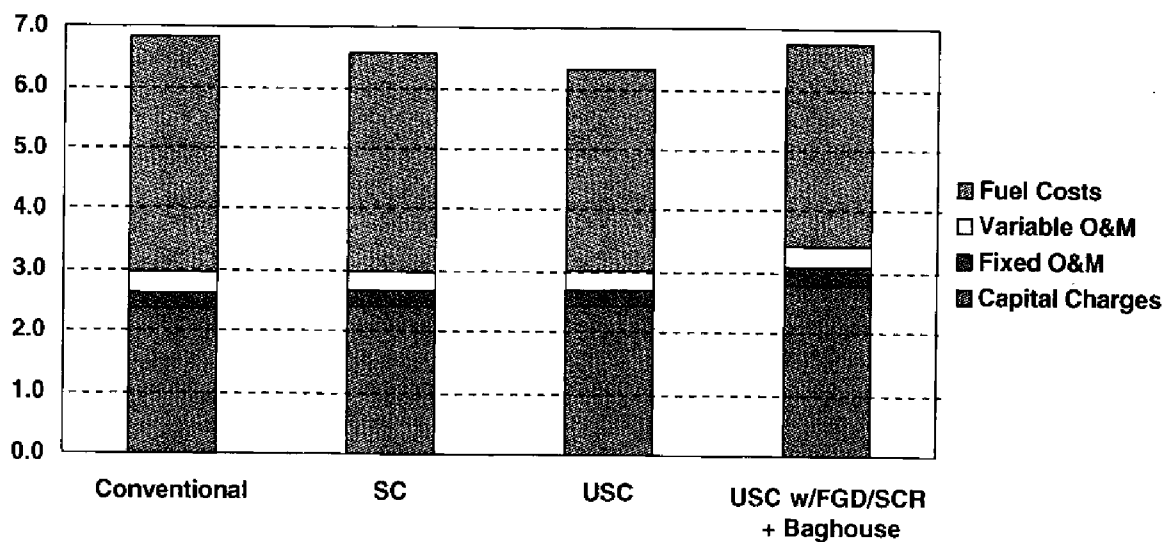


# Figure 9 (a)

## Cost of Electricity (cents/kWh)

Higher Fuel Cost (\$40/ton)

Higher Capital Cost Case

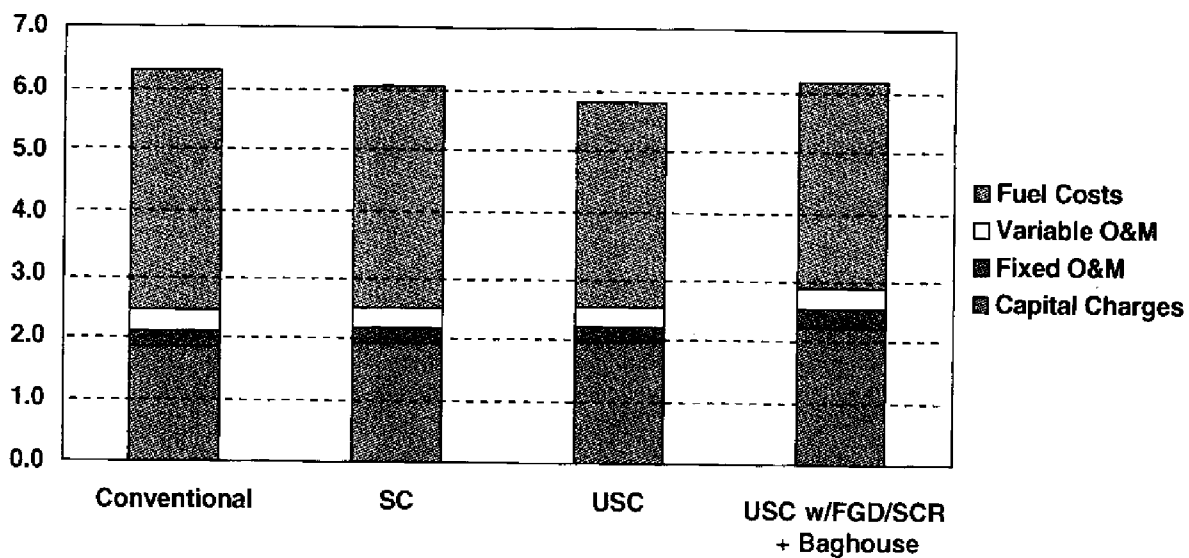


# Figure 9 (b)

## Cost of Electricity (cents/kWh)

Higher Fuel Cost (\$40/ton)

Lower Capital Cost Case



An economic analysis of subcritical versus supercritical state-of-the-art pulverised coal power plants, carried out for the CIAB by SEPRIL, has suggested that supercritical generation is less costly in terms of cost per kilowatt hour of electricity generated. This is especially marked for higher fuel cost but still significant for lower cost fuel.

Two types of action are being undertaken to overcome the perception barrier with regard to supercritical generating technology:

- (1) Development of communication among the stakeholders - governments, IPPs, major international construction engineering companies and technology suppliers - to confirm the cost and reliability figures for supercritical versus conventional subcritical technology;
- (2) Discussion with financing entities - private banks, multilateral funding organisations, and government export credit agencies - to identify the risk issues and possible creative financing incentives which would encourage the use of more efficient generating technologies.

## REFERENCES

1. *Development Plan for Advanced Fossil Fuel Power Plants*, EPRI Report CS-4029, Bilber Associates, 1985.
2. *Turbine Designs for Improved Coal-Fired Power Plants*, EPRI Research Project 1403-15, TR-100460, General Electric Company and Toshiba Corporation, edited by Encotech Inc., 1991.
3. *The Advanced Pulverised Coal-Fired Power Plant: Status and Future*, S. Kjaer, Elsamprojekt, 1994 ASME, International Power Generation Conference (PWR-40).
4. Keynote lecture of the VGB Conference, Kolding June 93, S. Kjaer - Elsamprojekt, H. Koetzier and J. van Liere - KEMA and I Rasmussen - Midkraft Power Company, Aarhus DK.
5. *Newly Developed High Temperature Ferritic-Martensitic Steels from USA, Japan and Europe*, R. Blum, Faelleskemiderne, Fynsværket, Odense, Denmark, et al., 1993 International VGB Conference Fossil-Fired Power Plants with Advanced Design Parameters.
6. *Development of Improved Boiler Startup Valves*, EPRI Report GS-6280, April 1989.
7. *Particle Erosion Technology Assessment*, EPRI Report TR-103552, December 1993.
8. *Circumferential Cracking of the Waterwalls of Supercritical Boilers*, EPRI Report TR-104442, September 1995.
9. *World Energy Outlook*, International Energy Agency, OECD, Paris 1996